Renewable and Sustainable Energy Reviews 39 (2014) 394–402

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

An integrated on-farm production system: Agricultural briquettes for residential heating in Nova Scotia, Canada

Kenneth W. Corscadden *, Jaclyn Biggs, Allan Thomson

Faculty of Agriculture, Department of Engineering, Dalhousie University, PO Box 550, Truro, Nova Scotia, Canada, B2N 5E3

ARTICLE INFO

Article history:
Received 21 November 2013
Received in revised form
29 May 2014
Accepted 7 July 2014
Available online 1 August 2014

Keywords:
Agricultural biomass briquettes
Energy policy
Economic feasibility

ABSTRACT

Agricultural biomass is emerging as a sustainable and suitable resource for use in the production of solid fuel, designed for residential markets. The development of such a fuel source faces several challenges including combustion properties, a reliable supply of raw materials, distance from and access to conversion facilities, production scale and market access for agricultural biomass products. This paper evaluated the economic feasibility of an “integrated on-farm production system” based in Nova Scotia, Canada and considered the importance and influence of policy on the development of a sustainable on-farm production system. This integrated approach is evaluated with input and output based incentive models, both of which are currently available in the USA and Prince Edward Island, Canada. The results indicate that the development of an integrated on-farm approach, while showing promise, will require policy implementation and pragmatic incentives to be truly sustainable. It is proposed that the benefits to the agricultural sector, rural communities and the environment should outweigh the costs of such incentives.

Contents

1. Introduction

There is a global drive to reduce greenhouse gas (GHG) emissions with National and International agreements and policies in place among the vast majority of developed and increasingly, developing countries [1,2]. One key method of mitigating GHG emissions is through the reduction of fossil fuel powered electrical generation, a goal that is supported in many developed countries such as Canada, USA, UK and Australia by renewable energy strategies and road maps [3–6]. A shift toward the generation of electrical energy from renewable sources is a vital component of such renewable energy strategies, with generation typically achieved using a range of technologies including hydro, solar, on/offshore wind and biomass through combined heat and power

* Corresponding author. Tel.: +1 902 893 6715; fax: +1 902 893 1859.
E-mail address: Kenneth.corscadden@dal.ca (K.W. Corscadden).

http://dx.doi.org/10.1016/j.rser.2014.07.075
1364-0321/

plants (CHPs). It is anticipated that biomass, both forestry and agriculture, will play a dominant role in the future global energy mix [7]; however barriers and uncertainties exist relating to land use, global demand for energy and the impact of bioenergy growth on food, energy and the environment [8]. Meyer et al. conclude that the optimisation of biomass supply chains may overcome these barriers and uncertainties and ultimately contribute to the economic and sustainable use of biomass [9]. Mani et al. [10] report economies of scale in biomass pellet production up to 75,000 T/yr. (Ton per year) with an average pellet mill output capacity of 150,000 T/yr. Thus, the majority of research to date addresses supply chain development in 75,000–200,000 T/yr range. Biomass supply chains have six key operations which encompass, production, harvesting, collection, pre-treatment, storage and conversion [11]. An important component of biomass supply chains is the transportation of material between each of the six operations, a factor that introduces constraints in the development of an "economically optimised" supply chain. Although this varies by scale, material and country, an extensive study produced for the Ontario Federation of Agriculture proposes economical transportation distances of 400–500 km for centralised power plants and 200–250 km for distributed power generation [12]. This distance will need to reduce considerably when dealing with "small scale" biomass production systems.

There is potential to further reduce GHG emissions through the adoption of biomass space heating strategies particularly in regard to residential dwellings and the development of an appropriately scaled supply chain [12]. Residential space heating is a substantial industry worldwide, accounting for 55%, 63% and 83% of total energy used in the residential sector in the UK [14,15], the United States [16], and Canada [17], respectively. The high energy requirement in Canada is attributed to colder climatic conditions, with the average distribution of residential heating sources reported as natural gas (47%), electricity (37%), oil (9%), wood biomass (6%) and propane (1%) [18]. In Nova Scotia (NS), a small eastern Canadian province, natural gas availability is limited and fuel source distribution is reported as: oil (55%), electricity (25%) and wood biomass (20%) [19]. It would appear that there is a growing opportunity for residential space heating using biomass, however the development of such markets will be impacted by energy strategies and government policy.

Several Provinces and Territories within Canada have developed 'Energy Strategies' but with wide variations in the contribution of bioenergy in such plans. The Yukon Energy Strategy highlights forestry biomass as a potential resource with plans for expansion and development [19]; however no formal structure is in place to achieve this. In contrast, the Northwest Territories have established a working Biomass Energy Strategy which clearly outlines plans for the development of a provincial bio-economy [20]. The Energy Strategy in British Columbia identifies both forestry and agriculture as key resources and includes a roadmap for the development of a bio-economy by 2020 and has already established a Bioenergy Network [21]. Manitoba's Bio-products Strategy [22] and Alberta's Nine-Point Bio-energy Plan [23] both recognise the potential role of agricultural crops and crop residues as viable resources. The Energy Strategy in Prince Edward Island (PEI) clearly outlines the use of bio-energy for combustion, biofuels and biogas and similarly recognises the contribution from agricultural resources [24].

The Canadian Bioenergy Association highlights significant regulatory hurdles and barriers inherent in the aforementioned energy strategies [25], with particular attention paid to the Atlantic Provinces, stating that with the high use and high price of heating oil, the provinces need to hasten state-of-the-art bioenergy technologies and develop a 'Regional Bioenergy Industry Group', neither of which has happened to date. New Brunswick (NB) and NS both have existing policies relating to forestry biomass with some strategic suggestions for forestry proposed by the NB Energy Commission [26]. The Energy Strategy in NS [27] makes little mention of biomass, with the view that although biomass is recognised as a resource, significant further work is required to identify the associated costs and subsequent sustainability within the province. The Natural Resources Strategy (covering forestry) [28] has however incorporated elements that align with the NS Renewable Electricity Plan [29], but the main use of forestry biomass is intended primarily for electricity generation at the distribution or centralised generation scale.

Current and future competing demands for forestry biomass create an opportunity for agriculture. Agricultural or herbaceous biomass is an underutilised resource [30,31]; however the integration of this resource particularly when applied to residential combustion faces several challenges. Herbaceous biomass inherently contains alkali metals and inorganic elements such as potassium, sulphur and chlorine which when combusted results in clinkers (which tend to extinguish a fire), high ash, corrosive gases and particulate emissions [32–35]. Progress has been made by a number of researchers which address the combustion issues with agricultural biomass [36] and this paper builds upon this work by investigating the potential development of an agricultural based solid fuel production system that is both economical and sustainable by creating a biomass briquette for residential wood stoves [37]. Briquettes, or energy logs, are densified forms of biomass that are much easier to produce than pellets. Energy logs are available in many hardware stores and, like wood pellets, are commonly produced from waste wood streams, with the addition of specialty logs which are produced from waste paper, coffee and non-petroleum based waxes. The manufacturing process for energy logs requires intense pressure and heat, but unlike pellet production uses a much larger die and only requires a one step process using a pneumatic press, which significantly reduces the complexity, labour requirements, energy use and ultimately, production costs of energy logs.

There are three main components associated with biomass products for residential heating applications, which include: (1) supply (quality and quantity of raw material), (2) product (conversion and processing of raw material) and (3) demand (market for biomass fuel). The same generic criteria can be applied to both forestry and agricultural biomass products. The market for wood pellets and wood briquettes sold for use in wood pellet stoves or wood stoves is well developed. The same is currently not true in NS for agricultural biomass products. There is currently lack of demand (no market) for agricultural biomass fuel, a factor which is due in part to combustion challenges, knowledge and awareness. This lack of demand impacts supply with virtually no agricultural crops currently grown for fuel feedstock and consequently, there is limited processing infrastructure available within the province, with the major deterrents including lack of financial capital, the ongoing regulatory costs/requirements and the cost of biomass, such as the price and transportation costs [38]. As such,

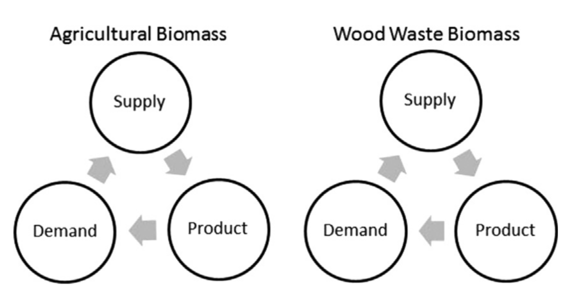

Fig. 1. Mutually exclusive markets for wood and agricultural based biomass fuel products.

the supply and demand for wood and agricultural biomass fuel can be considered mutually exclusive as demonstrated in Fig. 1.

The paper proposes an appropriately scaled on-farm production system, referred to as an "integrated on-farm approach" to this dilemma, which involves the creation of fuel from agricultural biomass, in a form that is suitable for combustion in any residential wood burning stove. The proposed scale of such an enterprise is anticipated to be in 200–1000 T/yr range, much smaller than typical commercial biomass conversion systems of 150,000 T/yr [10]. The agricultural biomass would be grown, harvested, processed and converted on-farm, with appropriately scaled equipment, using biomass which is a by-product of crops currently grown on farm or dedicated energy crops. The development of on-farm processing would remove the transportation costs (currently estimated to be 10–18% of agricultural biomass production [11]), creating an alternative product suitable for existing residential markets and serving the current demand for wood briquettes, Fig. 2. This integrated on-farm production system would result in a supply chain without transportation constraints (with the exception of distributed sales) providing two sales options, direct at farm gate or through local distributors, resulting in a supply chain, Fig. 3.

In 2011, 27% of all household heating in Nova Scotia came from wood and wood pellets, representing 10,810 TJ of energy, with an average of 75 GJ per household [39]. This substantial market for residential heating fuel presents an opportunity for the integration of additional feedstock from agriculture and is the target of this research. The impact of such a venture is yet to be determined; however, the Agri-food industry in NS, in 2010, employed 10,575 people with 5800 in primary agriculture [40] across 4000 farms utilising 403,044 ha [41]. Large proportions of this land have the potential for exploitation as a sustainable biomass resource, without competing for food production. The NS Federation of Agriculture (NSFA) currently has a standing policy for the encouragement, promotion and research of energy related issues and is actively pursuing and willing to expand the environmental and energy remit [42]; this provides a good starting framework for the development of agricultural biomass within the province. This paper considers the impact that policy driven incentives or subsidies may have on the profitability of integrated on-farm biomass production in NS, by considering two currently available policies utilised in the USA [43] and PEI [44].

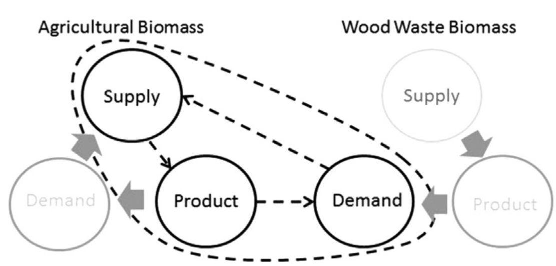

Fig. 2. Integrated on-farm agricultural biomass product, competing with wood briquettes.

2. Material and methods

The methodology employed in this paper uses both primary and secondary data to evaluate the potential feasibility of an appropriately scaled integrated on-farm approach for the production in NS of an agricultural briquette fuel. The economic viability is examined for three different policies using four base feedstocks, actual and estimated manufacturing costs and equipment constraints, which are listed in Table 1 and in the section entitled "Model Assumptions". The three policy cases are defined as, (i) without policy driven incentives, (ii) with policy incentives that provide support based on production output. An example of such an incentive is the Biomass Crop Assistance Program (BCAP) [43], available to farmers in the USA and provides $45/ton of biomass produced, and (iii) with policy incentives that provide rebates of 25%, 50%, and 75% of input costs. An example of this policy incentive is the Bioeconomy Crop Initiative [44] offered in PEI.

This research utilises four feedstocks common in NS, identified as, Reed canarygrass (RCG), Switchgrass (SWG), barley straw and hay which have been obtained from local farms. The production costs, including labour, energy use and yield have been determined by producing briquettes from each of the four feedstock at the biomass conversion pilot facility at the BioEnvironmental Engineering Centre (BEEC), Dalhousie University's Faculty of Agriculture. The conversion process utilises equipment commonly found on agricultural operations, demonstrated by the flow chart in Fig. 3. A Total Mix Rotation (TMR) mixer was used to reduce a whole round bale to 3–6 in. (7.5–15 cm), which was then fed to a Holland hammer mill, driven using a tractor power take off (PTO), with a ¼ in. (6.35 mm) screen to reduce the feedstock to a fine fibre (1–2 mm in width and 1–1.5 cm in length). The four feedstocks were converted into 2 in. (50 mm) diameter briquettes using a Weima C 150 Briquette press [45]. The briquette machine employs a hopper with an agitator and augers feedstock into a pressing chamber. An integrated hydraulic system compresses the feedstock at pressures of up to 2600 psi applied through a piston. For the economic analysis, it is assumed that RCG and SWG are planted and grown specifically as energy crops. Barley straw is a by-product from the growth of barley grain and hay is grown as a lower value energy crop on marginal or underutilised agricultural land. A slightly larger press was also used for the analysis, a Wiema TH 1500 [45], with a higher throughput. Manufacturer's specifications were used for energy requirements for the press and yield from the pilot C150 press was used as realistic production capacity.

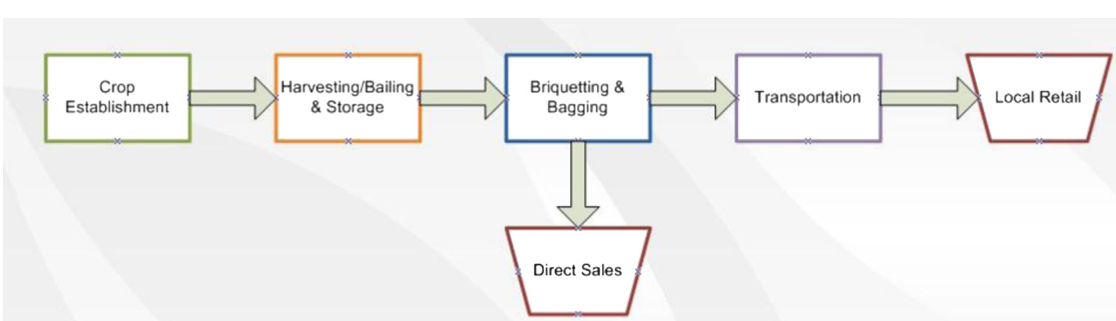

Fig. 3. Proposed supply chain development of integrated on-farm production system.

Table 1
Costs and yields expected for each feedstock.

	SWG	RCG	Hay	Barley
Typical yields expected in Nova Scotia	**2.2**	**2.4**	**2**	**1**
Harvesting costs	**\$/acre**	**\$/acre**	**\$/acre**	**\$/acre**
Fertilizer (150 lb/acre of 34-0-0@775/T, spreading)	58.00	58.00	48.50	0
Mow conditioner (6.0 acres/h @ \$90/h)	15.00	15.00	0	0
Tedding (10 acres/h. @ \$64/h)	6.50	6.50	10.00	0
Racking, hauling and unloading	32.00	32.00	34.00	20.00
Round baler (5 acres/h @ \$100/h)	40.00	40.00	33.00	40.00
Land rental	50.00	50.00	50.00	50.00
	201.50	**201.50**	**175.50**	**110.00**
Processing costs	**\$/ ton**	**\$/ ton**	**\$/ ton**	**\$/ ton**
Operating cost of briquette machine (electricity)	13.20	13.20	13.20	13.20
Operating cost of hammer mill (Diesel Fuel)	12.00	12.00	12.00	12.00
Wrapping – plastic and bags (packaging)	2.89	2.89	2.89	2.89
Wrapping – labour & equipment rental	18.11	18.11	18.11	18.11
Other misc. costs (\$/ton)	2.00	2.00	2.00	2.00
Labour (briquetting/hammer mill)	31.72	31.72	31.72	31.72
	79.40	**79.40**	**79.40**	**79.40**
Fixed Costs	**(\$/year)**	**(\$/year)**	**(\$/year)**	**(\$/year)**
Equipment – briquette machine	13712	13712	13712	13712
Equipment maintenance and repair	1150	1150	1150	1150
Equipment – hammer mill	500	500	500	500
Truck/trailer	500	500	500	500
Establishment	43.35	43.35	43.35	43.35
	15362	**15362**	**15362**	**15362**

The objective of the analysis is to determine the impact on policy and profitability of producing and converting feedstock locally at a suitable scale using agricultural biomass. Two scenarios were examined for each of the four feedstocks, subjected to the following policy cases:

(i) Without any policy driven incentives;
(ii) Policy that provides support based on output. Based on the Biomass Crop Assistance Program (BCAP) available to farmers in the USA, this incentive provides \$45/ton of biomass produced;
(iii) Policy that provides support based on input. Based on PEI's Bioeconomy Crop Initiative which provides rebates of 25%, 50%, or 75% of input costs.

The impact of these policies is examined on each of the four feedstocks, using the following two scenarios:

1. *Land use*. Identifying the amount of land that would need to be planted, harvested and maintained to provide a break even scenario, based on crop yields. The three policy scenarios highlight how policy can influence land use.
2. *Optimal process capacity*. The equipment utilised in this analysis has a maximum annual processing capacity of 665.6 T based on daily operating assumptions. (See Section 3). This scenario determines the profitability of processing at full capacity, based on the operational parameters and equipment constraints. The three policy scenarios highlight how policy impacts profitability of small scale operations, and inherently rural development and sustainability.

2.1. Potential revenue

The main competing products for an agricultural briquette are existing wood briquettes. Investigation of current retail prices of commonly available energy logs costs revealed substantial variation, ranging from \$1.50 to \$2.00/lb. Wood pellet prices were relatively less expensive than briquettes, however were found to be very similar between brands, mainly due to the demand for pellet fuel and competition between suppliers. A 40 lb bag of wood pellets was found to retail for \$5.99, discounted to \$5.49/bag for bulk purchases of 75 bags (1.36 T). A price of \$5.49 per bag equates to \$301.95 for 55 bags (1 T). Economic feasibility of the policy cases, feedstock and scenario was assessed assuming a conservative selling price for agricultural biomass briquettes of \$250.00 per metric tonne for a domestic market, or \$4.55 per 40 lb box. The costs associated with converting the feedstock into briquettes were categorised into three main components: crop production, processing and fixed. The model initially does not include any transportation costs as it is assumed that all material will be produced, converted on farm and sold at farm gate through direct sales. An additional scenario is presented which includes the impact of selling through local hardware stores.

3. Calculations

3.1. Crop production costs

Crop production costs included all variable costs associated with growing, fertilising, and harvesting (cutting, raking, baling and storage) for each of the feedstock. However, since it was assumed that barley straw was a by-product of grain production, only the baling and on-farm hauling costs were considered for barley harvesting with no planting or seeding costs assumed.

3.2. Harvesting costs

Harvesting costs are based on custom work, including labour and have been obtained through consultation with farmers and contract labourers in NS. The costs are reflective of labour costs in NS in 2013. It is assumed that all land has been rented.

3.3. Processing costs

Processing costs for all feedstock included the wrapping of the post-baled for storage, operating costs of the hammer mill and briquetting machine, all associated labour and packaging of the final product. Machinery costs have been obtained from the manufacturer. Energy requirements are based on manufacturer's specification. Baled crops are wrapped for storage using 6 mm 12 in. × 8 in. × 24 in. plastic wrap, at 80 bales/roll. It is assumed that, a tractor is available to operate the hammer mill, the briquetting machine operates for 8 h/day, 260 days/year, producing 665 T/yr (at 320 kg/h) and local electrical rates are 0.13/kw h (domestic tariff).

3.4. Fixed costs

Fixed costs include the capital costs for a Weima TH 1500 briquetting machine, hammer mill and trailer to transport material on-farm and the establishment costs of the feedstock. Fixed costs assumptions include briquetting machine ($110,000), annual maintenance at 1% of the capital cost, interest rates based on a 10 year fixed term of 4.55%, paid monthly. (Farm Loan Board, September 13, 2013), hammer mill and trailer ($5000 each), depreciated over 10 years.

Table 1 provides the crop production, processing, transporting and fixed costs for each of the feedstock, establishment costs of the energy crops depreciated over 10 years. Miscellaneous costs were assumed at $2/T.

The analysis presented in this paper compares the economic feasibility of agricultural briquette production without policy based incentive (which is currently the situation in NS), with two existing policy incentives, the US BCAP program and PEI's Bioeconomy Crop Initiative. The USA BCAP program provides a subsidy of $45/T for processed feedstock. PEI's Bioeconomy Crop Initiative is more complex and involves three components. The first promotes fall ryegrass as an energy crop. Since fall rye is typically not a common crop in NS, this component of the policy was not examined. The second promotes perennial biomass development through a 50% rebate on the input costs which include site preparation, cost of seed, planting, maintenance and harvesting. For analysis in this paper, it was assumed that only hay would be considered under this component. The third component promotes "novel crops". The use of these crops for biomass production can have a scaled rebate of up to 75%, 50%, 50% and 25% of the input costs during crop production years 1, 2, 3 and 4, respectively. Input costs include site preparation, cost of seed, planting, maintenance and harvesting. For analysis in this paper SWG and RCG are considered novel biomass crops. Barley straw does not fall under any of PEI's three components and thus is not considered in analysis of PEI's Bioeconomy Crop Initiative.

In addition to the policy analysis, the impact of direct distribution versus distributing through a local supplier is examined to determine the effect on profitability for each of the policies analysed.

4. Results and discussion

Economic analysis for each of the three policy cases has been achieved using the model assumptions defined above and the initial costs listed in Table 1, associated with growing SWG, RCG, barley straw and hay in NS. It is important to note that barley straw is considered a by-product of barley grain production, therefore the establishment costs, seeding and site preparation are not included in the harvesting costs. Also, SWG and RCG have the same costs associated with crop production, however it is noted that RCG typically has higher yields than SWG. The results of yield factor can be seen in the subsequent analysis.

The results of the economic analysis for Policy Case 1 (without subsidy) are presented in Table 2. Results reveal the acreage required for breakeven and for optimal production (where optimal production is determined by the maximum annual throughput of the briquetting machine based on the model assumptions and costs listed in Table 1). The results in Table 2 show that RCG has the highest yield and consequently requires fewer acres for breakeven, subsequently RCG also has the greatest profit associated with optimal operation. Barley straw is less profitable than other feedstocks; however it is assessed as a by-product and not grown specifically for energy production. The results in Table 2 show that 88, 73, 93 and 228 acres are required to breakeven for SWG, RCG, barley straw and hay, respectively. For optimal production, the land requirement increases to 303, 277, 640 and 333 acres for the four feedstocks, respectively, with an associated profit range of $27,786–$42,307. Thus, it is marginally profitable to grow SWG, RCG or hay for agricultural biomass in NS, without any policy incentives using an integrated on-farm production system.

Break-even and profitability analysis was also performed for Policy Case 2: BCAP, which provides support based on inputs. This policy provides an incentive of $45/T of biomass produced, the results of which are presented in Table 3.

The results in Table 3 show that the incentive of $45/T substantially impacts the profitability of agricultural briquette production. When compared to Policy Case 1, without subsidy, the acreage required to breakeven is reduced by 36%, 34%, 23% and 35% for SWG, RCG, barley straw and hay, respectively. The land use does not change for optimal production, as the maximum capacity of the machine is attained based on the time constraints stated in the assumptions. However, the profitability range when operating at full capacity increases substantially with the Policy Case 2, ranging between $57,738 and $72,261. This indicates that implementing a BCAP policy with an output based incentive would decrease the amount of land required to break even while increasing the profitability.

Table 2
Policy Case 1: without subsidy, comparison of the acreage required for break even and acreage and profit required for optimal production of 665 T/yr.

Feedstock	Yield (T/acre)	Policy Case 1: without subsidy			
		Breakeven		Optimal production 665 T/yr	
		Acres	Profit	Acres	Profit
SWG	2.2	88	$0	303	$37,224
RCG	2.1	73	$0	277	$42,307
Barley	1	228	$0	640	$27,786
Hay	2	93	$0	333	$39,780

Table 3
Policy Case 2: BCAP policy comparison of the acreage required for break even, profit target and full capacity for each of the feedstock with a $45/T subsidy.

Feedstock	Yield (T/acre)	Policy Case 2: BCAP, subsidy based on inputs			
		Breakeven		Optimal production	
		Acres	Profit	Acres	Profit
SWG	2.2	56	$0	303	$63,849
RCG	2.1	49	$0	277	$68,933
Barley	1	174	$0	640	$54410
Hay	2	60	$0	333	$64,404

Table 4
PEI's Bioeconomy Crop Initiative comparison of the acreage required for break even, optimal production capacity and profit, for novel crops, SWG and RCG.

	Policy Case 3: PEI Bioeconomy Novel Crop Initiative					
	75% year 1		50% years 2 and 3		25% year 4	
	Break even	Optimal production	Break even	Optimal production	Break even	Optimal production
Feedstock	Acres/profit	Acres/profit	Acres/profit	Acres/profit	Acres/profit	Acres/profit
SWG	53/$0	303/$71,601	62 /$0	303/$60,142	73/$0	303/ $48,683
RCG	48/$0	277/$73,818	54 /$0	277/$63,316	63/$0	277/ $52,812

Table 5
PEI's Bioeconomy Crop Initiative comparison of the acreage required for break even, optimal production capacity and profit for perennial crop, hay.

	Policy Case 3: 50%	
	Break even	Optimal production
Feedstock	Acres/profit	Acres/profit
Hay	67/$0	333/$60,663

Tables 4 and 5 presents the results for Policy Case 3, PEI's Bioeconomy Crop Initiative, which provides support based on input incentives. Table 4 contains the results for novel crops, SWG and RCG and Table 5 the results for hay, a perennial crop.

The results in Table 4 show that the 75% incentive changes the number of acres required to reach breakeven to 53 acres (year 1), 62 acres (years 2 & 3) and 73 acres (year 4) for SWG and 48 acres (year 1), 54 acres (years 2 & 3) and 63 acres (year 4) for RCG. The acreage required for optimal production remains unchanged, but profit increases to $71,601 (SWG) and $73,818 (RCG) for year 1, but drops significantly to $48683 (SWG) and $52812 (RCG) for year 4 onwards; thus, the incentives in years 1–3 appear to be solely designed to provide establishment support. The results presented in Table 5 relate to hay as a perennial crop with a fixed subsidy of 50%. This reduces the amount of land required to break even to 67 acres, compared to 93 acres that are required without subsidy for optimal production. It also increases profit significantly to $60,663.

One objective of this research is to investigate the potential that policy may have on land use. Fig. 4 presents the acreage required for each feedstock as a function of the three different policy cases for breakeven and optimal production. The results presented in Fig. 1 show that policy has limited impact on the amount of land required for breakeven. RCG, SWG and hay require similar acreage for each policy, with barley straw requiring the largest amount of land. Policy influences result in a significant change, however at optimal production, requiring 277 acres (RCG), 303 acres (SWG) and 333 acres (hay). In NS, where farms are quite diverse and small, access to this amount of land is reasonable. Since Barley straw was deemed a by-product of grain production, it requires double the land (640 acres) to achieve breakeven.

Fig. 5 highlights the impact that the three policy cases have on net profit for each feedstock under the conditions of optimal production. For Policy Case 1, without subsidy, the results indicate that an integrated on-farm production system is economically feasible, with the largest gross profit of $42,307 obtained for RCG. Hay is also feasible with an estimated annual profit of $39,780. Hay is potentially a more diverse crop with lower establishment costs than specified ‘energy crops’ and has alternative uses than agricultural biomass. Even barley straw, a by-product of barley production, has potential to be profitable under optimal production conditions. The input based subsidy provided by PEI has significant benefit for hay production, but a lower benefit for the energy crops of RCG and SWG. The greatest gross profit, however is obtained using the input based subsidy offered in the USA through the BCAP program which provides an increase in gross profit of 63%, 72%, 67% and 96% for RCG, SWG, hay and barley straw, respectively when compared to Policy Case 1, without subsidy.

Sensitivity analysis was also performed to determine the impact that a change in yield and selling price would have on potential profits, under optimal production for each of the policy cases. Profit sensitivity was assessed for both $+/-10\%$ variation in yields over the original yield assumptions for each feedstock. Table 6 highlights these results. As indicated, for Policy Case 1, a 10% change in yield results in a 31%, 27%, 39%, 42% change in profit for SWG, RCG, barley and hay, respectively. For Policy Case 2, a 10% change in yield results in a 22%, 20%, 25% and 33%, respectively. Thus, profit sensitivity to yield variations is somewhat buffered through the BCAP policy which pays a subsidy based on output, therefore potential profits increase even though yields are lower. Yet, as seen in Policy Case 3, a 16% change in profit is realized in year 1, 19% in year 2, and a 23% change in year 4 for SWG, while RCG has 15%, 18% and 22% change for years 1 through 4, respectively. Hay was similar, with a 19% change in profit. Thus, Policy Case 3 lowers the impact even further to yield variations since this subsidy is based on inputs, rather than output which decreases the yield sensitivity.

When examining the effects of selling price on profit, similar results are obtained. Table 7 shows a $+/-$ 10% variation in selling price to $225/T and $275/T using the original yield assumptions for each feedstock. With Policy Case 1, changes of 45%, 39%, 60% and 42% in SWG, RCG, barley and hay, respectively were realized from a 10% change in selling price. Analysis of Policy Case 2 shows a 26%, 24%, 31%, 29% change in SWG, RCG barley and hay, respectively, while SWG and RCG ranged between 23–34% and 23–32%, respectively for years 1 through 4 for Policy Case 3, while hay resulted in a 27% change in profit. Thus a change in selling price had similar effects on profitability for all three policy cases. Overall, these are greater results than from sensitivity analysis with respect to yield, indicating that profitability is influenced greater by a change in selling price than by a change in yield, for all policy cases.

Table 7 shows the effect a reduction in selling price has on profit, using the original yield assumptions. The PEI 75% incentive and the BCAP $45/T incentive were similar in terms of impact on profitability. However, in a year when crop yields are low, due to weather or other environmental factors, yields will decrease and profitability will diminish. Since yields will reduce, so also will the amount received from the BCAP program. However, with PEI's program, an incentive based on input costs, yields do not impact the subsidy received. The subsidy would only decrease as a result of a reduction in acreage used for production, or if the input costs decreased (which has not been the trend in recent years).

The development of an appropriately integrated on-farm production system in NS can be profitable and have significant impact on land use. There are currently an estimated 165,000 ha of

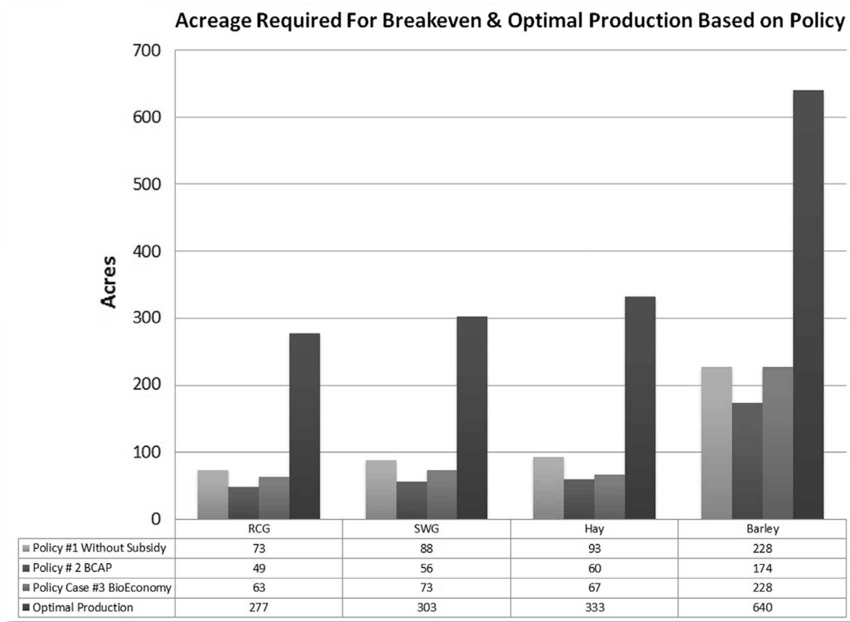

Fig. 4. Impact of the three policy cases on land use.

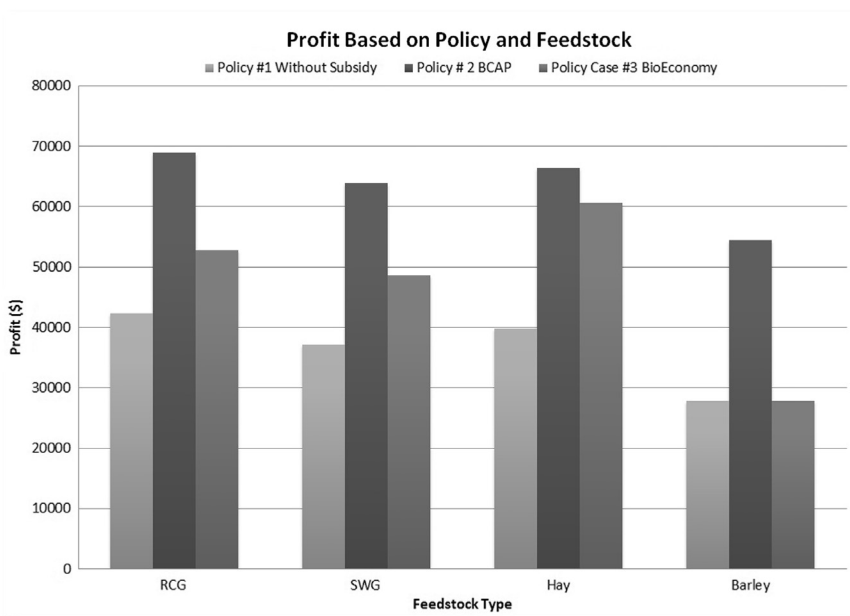

Fig. 5. Impact of three policy cases on gross profit obtained for optimal production.

Table 6
Sensitivity analysis of yield on profit, using +/−10% variation, for each policy case.

Crop	Change in original yield (%)	Yield (T/acre)	Policy Case 1 profit ($)	Policy Case 2 profit ($)	Policy Case 3 profit ($)		
					Year 1	Years 2 & 3	Year 4
SWG	+10	2.42	48579	77866	82956	71497	60038
	−10	1.98	25869	49831	60246	48787	37328
RCG	+10	2.64	53663	82951	85176	74672	64167
	−10	2.16	30952	54915	62465	51961	41456
Barley	+10	1.14	38704	67888	N/A		
	−10	0.94	16431	30768	N/A		
Hay	+10	2.20	56420	85706	72017		
	−10	1.80	23140	47101	49308		

Table 7
Sensitivity analysis of selling price, using +/−10% variation in selling price and original.

Crop	Yield	Change in selling price (%)	Selling price ($/T)	Policy Case 1 profit ($)	Policy Case 2 profit ($)	Policy Case 3 profit ($)		
						Year 1	Years 2 & 3	Year 4
SWG	2.20	+10	275.00	53864	80489	88242	76782	65323
		−10	225.00	20584	47208	54961	43502	32043
RCG	2.40	+10	275.00	58948	85574	90462	79957	69453
		−10	225.00	25666	52292	57180	46675	36170
Barley	1.02	+10	275.00	44426	71050	N/A		
		−10	225.00	11146	37770	N/A		
Hay	2.00	+10	275.00	56420	83044	77303		
		−10	225.00	23140	49764	44023		

Table 8
Amended profit for each of the three policy cases with additional costs for distribution and sales.

Distribution & sales	RCG	SWG	Hay	Barley
Optimal production (acres)	277	303	333	640
Transportation costs ($)	5493	5493	5493	5493
Distribution mark up ($)	33250	33250	33250	33250
Profit Policy Case 1 ($)	3564	−1519	1037	−10957
Policy Case 2 ($)	30190	25106	27661	15667
Policy Case 3 ($)	14066	9940	21920	−10957

agricultural land in NS, of which 15% is actively farmed [46]. The analysis presented in this paper has the potential to encourage the transformation of this land to crop production. There are also additional benefits including the potential for employment and rural sustainability. Each integrated on-farm production system could utilise 300 acres of land, generate $40,000 of profit and create one full time job, if operated at optimal production. Even if the farm only processed half the maximum capacity, this would still create additional employment which could be carried out by seasonal workers, if scheduled during the off season (i.e. winter). This would help increase job security and reduce the dependence of seasonal workforce demands on the unemployment insurance programme.

Another issue for an integrated on-farm production system is the scale of operation. If the Weima TH 1500 briquetting machine was utilised, as suggested in this analysis, the acreage required for maximum throughput and associated profit were reasonable for the province's size (as shown in fig. 4). Increasing the scale of production would involve increasing equipment size and also increasing acreage required to operate at maximum throughput. This may cause an issue relating to the ability to secure sufficient supply, especially within one region of the province. If insufficient land is not available in one region then utilising land from multiple and/or disperse regions raises the issue of transportation of raw material to a processing site. Biomass raw material is an extremely bulky product and additional transportation costs will impact profitability.

Analysis thus far has focussed on the potential economic feasibility of an integrated on-farm production system, involving crop production, processing and sales all occurring on-farm. The challenges of further expansion or additional distribution routes create the problems associated with many biomass models and assessments which ultimately demand large scale production to achieve profitability. Additional analysis, where the operation is still on-farm, but sales are achieved through local hardware stores, is now considered. This will have an impact on profitability with an increase in variable costs for transportation and markup for the store. It is assumed that transportation will be within a local radius of 100 km return trip and that the truck and trailer are capable of transporting 5 T per trip. It is also assumed that the store will require a 25% mark up on the product, therefore reducing the revenue to $200/T. The modified profit analysis is listed in Table 8.

As shown, the impact of selling through a distributer, combined with the transportation costs associated with that has substantial impacts on profitability. As shown, with no policy (Policy Case 1), a farm would barely break even when processing at optimal production. With Policy Case 2, the BCAP policy, profitability decreases substantially for all four feedstocks. Policy Case 3, the input based policy, again decreased profitability substantially, creating a loss for barley straw.

5. Conclusions

The development in NS of an integrated, on-farm production system for agricultural biomass briquettes is economically feasible using the assumptions and constraints presented in this paper. NS has the available resources in which underutilised or marginal land can be employed for alternate uses in a profitable manner. The implementation of policy can substantially influence and promote the development of such an industry, with additional rural and economic benefits. However, clear policy goals must be developed before implementation to ensure the desired results will be achieved. Policy should consider the impact on market development, transportation, production scale and policy incentive levels.

References

[1] United Nations. Kyoto Protocol to the United Nations Framework Convention on Climate Change. United Nations; 1998.

[2] United Nations . Conference of the Parties to the United Nations framework convention on climate change.The Copenhagen Accord of 18 December 2009, Available from: ⟨http://unfccc.int/resource/docs/2009/cop15/eng/l07.pdf⟩; 2009 [Accessed 11.15.13].

[3] Ministry of Energy, Mines and Petroleum Resources, Canada. BC bioenergy strategy: growing our natural energy advantage, Available from: ⟨http://www.energyplan.gov.bc.ca/bioenergy⟩; 2012 [Accessed 05.02.15].

[4] Bioenergy Interagency Working Group, USA. Bioenergy action plan, Available from: ⟨http://www.resources.ca.gov/docs/2012_Bioenergy_Action_Plan.pdf⟩; 2012 [Accessed 05.02.14].

[5] Department of Energy and Climate Change, UK. Renewable energy roadmap, ; Available from:⟨https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48128/2167-ukrenewable-energy-roadmap.pdf.⟩; 2011[Accessed 11.15.13].

[6] Australian Government – Clean Energy Council. Australian bioenergy roadmap, Available from: ⟨http://www1.eere.energy.gov/bioenergy/pdfs/mypp_november_2011.pdf⟩; 2008 [Accessed 11.02.13].

[7] Rentzelas AA, Tolis AJ, Tatsiopoulos IP. Logistics issues of biomass: the storage problem and the multi-biomass supply chain. Renew Sustain Energy Rev 2009;13:887–94.

[8] Popp J, Lakner Z, Harangi-Rakos M, Fari M. The effect of bioenergy expansion: food, energy and environment. Renew Sustain Energy Rev 2014;32:559–78.

[9] De Meyer A, Cattrysse D, Rasinmake J, Van Orshoven J. Methods to optimise the design and management of biomass-for-bioenergy supply chains: a review. Renew Sustain Energy Rev 2014;32:559–78.
[10] Mani S, Sokhansanj S, Bi X, Turhollow A. Economics of producing fuel pellets from biomass. Appl Eng Agric 2006;22(3):421–6.
[11] Wee HM, Yang WH, Chou CW, Padilan MV. Renewable energy supply chains, performance, applications barriers and strategies for further development. Renew Sustain Energy Rev 2012;16:5451–65.
[12] Assessment of Business Case for Purpose –Grown Biomass in Ontario, ⟨http://www.ofa.on.ca/uploads/userfiles/files/assessment%20of%20business%20case%20for%20purpose-grown%20biomass%20in%20ontario%20march%202012.pdf⟩ [Accessed 05.07.14].
[14] Government of UK. Renewable Heat Incentive, Available from: ⟨https://www.gov.uk/government/policies/increasing-the-use-of-low-carbontechnologies/supporting-pages/renewable-heat-incentive-rhi⟩; 2011 [Accessed 11.15.13].
[15] Department of Energy and Climate Change. Energy consumption in the UK: Chapter 3: Domestic factsheet. Available From: ⟨https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65954/chapter_3_domestic_factsheet.pdf⟩; 2013 [Accessed 05.07.14].
[16] US Department of Energy. Building energy data book – 2011. USA: Pacific Northwest National Library; 2011.
[17] Energy Use Data Handbook – 1990 to 2009. Canada: Crown Corporation; 2011.
[18] Statistics Canada. Households and the environment: energy use, Available from: ⟨http://www.statcan.gc.ca/pub/11-526-s/11-526-s2010001-eng.pdf⟩ ; 2007 [Accessed 11.15.13].
[19] Government of Yukon. Yukon energy strategy, Available from: ⟨http://www.energy.gov.yk.ca/energy_strategy.html⟩; 2009 [Accessed 10.10.13].
[20] Northwest Territories. Northwest Territories: biomass energy strategy – 2012–2015, Available from: ⟨http://www.enr.gov.nt.ca/_live/documents/content/Biomass_Energy_Strategy_2012-2015.pdf⟩; 2012 [Accessed 10.10.13].
[21] British Columbia – Ministry of Energy, Mines and Petroleum Resources. BC bioenergy strategy: growing our natural energy advantage, Available from: ⟨http://www.energyplan.gov.bc.ca/bioenergy/PDF/BioEnergy_Plan_005_0130_web0000.pdf⟩; 2008 [Accessed 10.09.13].
[22] Government of Manitoba. The Manitoba bioproducts strategy, Available from: ⟨http://www.gov.mb.ca/agriculture/pdf/the_manitoba_bioproducts_strategy.pdf⟩; 2012 [Accessed: 10.11.13].
[23] Government of Alberta. Alberta's nine-point bioenergy plan, Available from: ⟨http://www.energy.gov.ab.ca/pdfs/BioE9pointPlan.pdf⟩; 2008 [Accessed 10.10.13].
[24] PEI. Prince Edward Island energy strategy. Securing our future: energy efficiency and conservation, Available from ⟨http://www.gov.pe.ca/photos/original/env_snergystr.pdf⟩; 2008 [Accessed 05.07.14].
[25] McCallum B. Addressing barriers restricting bioenergy system applications in Canada. Prince Edward Island: Canadian Bioenergy Association; 2008.
[26] Volpe J, Thompson WM. Final report: New Brunswick Energy Commission 2010-2011. New Brunswick: New Brunswick Energy Commission; 2012.
[27] Towards a greener future: Nova Scotia's 2009 energy strategy. Nova Scotia: Nova Scotia Department of Energy; 2009.
[28] Nova Scotia: Government of Nova Scotia; 2009.
[29] Province of Nova Scotia. Renewable electricity plan, Available from: ⟨http://novascotia.ca/energy/renewables/renewable-electricity-plan/default.asp⟩; 2010 [Accessed .11.15.13].
[30] Field CB, Campbell JE, Lobell DB. Biomass energy: the scale of thepotential resource. Trends Ecol Evol 2008;23(2):65–72.
[31] Li X, Mupondwa E, Panigrahi S, Tabil L, Sokhansanj S, Stumborg M. A review of agricultural crop residue supply in Canada for cellulosic ethanol production. Renew Sustain Energy Rev 2012;16:2954–65.
[32] Johansson LS, Tullin C, Leckner B, Sjovall P. Particle emissions from biomass combustion in small combustors. Biomass Bioenergy 2003;25:435–46.
[33] Obernberger I, Biedermann F, Widmann W, Riedl R. Concentrations of inorganic elements in bio-mass fuels and recovery in different ash fractions. Biomass Bioenergy 1996;12-3:211–24.
[34] Johansson LS, Tullin C, Leckner B, Sjovall P. Particle emissions from biomass combustion in small combustors. Biomass Bioenergy 2003;25:435–46.
[35] Bäfver LS, Leckner B, Tullin C, Berntsen M. Particle emissions from pellets stoves and modern and old-type wood stoves. Biomass Bioenergy 2011;35:3648–55.
[36] Ravichandran P, Gibb D, Corscadden KW. Controlled batch leaching conditions for optimal upgrading of agricultural biomass. J Sustain Biomass Bioenergy: Sci Res 2013;3:186–93.
[37] Roy M, Corscadden K. An experimental study of combustion and emissions of biomass briquettes in a domestic wood stove. Appl Energy 2012;99:206–12.
[38] Statistics Canada. Table 5. Barriers to production or development of bioproducts, Canada, 2009, Available from: ⟨http://www.statcan.gc.ca/pub/88f0006x/2011001/t021-eng.htm⟩; 2013 [Accessed 10.29.13].
[39] Statistics Canada. Households and the environment: energy use 2011, Available from: ⟨http://www.statcan.gc.ca/pub/11-526-s/11-526-s2013002-eng.pdf⟩; 2013 [Accessed 10.29.13].
[40] Devanney M, Reinhardt F. An overview of the Nova Scotia agriculture and agri-food industry. Nova Scotia: Nova Scotia Department of Agriculture; 2010.
[41] Homegrown success: a ten year plan for agriculture. Nova Scotia: Nova Scotia Government; 2011.
[42] Nova Scotia Federation of Agriculture. Nova Scotia federation of agriculture – standing policy 2012– 2013, Available from: ⟨http://nsfa-fane.ca/wp-content/uploads/2012/05/Policy-2013_NEWSLETTER.pdf⟩; 2012 [Accessed -09.24.13].
[43] National Sustainable Agriculture Coalition. Biomass Crop Assistance Program. N.d; Available from: ⟨http://sustainableagriculture.net/publications/grassrootsguide/renewable-energy/biomass-crop-assistance-program/⟩. [Accessed 10.02.13].
[44] Government of PEI. Bioeconomy crop initiative. Available from: ⟨http://www.gov.pe.ca/photos/original/af_flex_bioprog.pdf⟩; 2001 [Accessed 10.02.13].
[45] WEIMA Maschinenbau GmbH. TH 1500-briquette press, Available from: ⟨http://weima.com/usa/machinery/briquette-presses/th1500-3400-series/th1500.html⟩; 2013 [Accessed 09.16.13].
[46] Province of Nova Scotia. On Nova Scotia farms – a teacher's guide to agriculture. Nova Scotia: Nova Scotia Department of Agriculture; 2012.